First-Year Progress Report for NASA Grant NAGW-2887

Period of Performance: This report covers the period from April 1, 1996 to date.

Scientific Objectives

The upper mesosphere and lower thermosphere (MLT) is unique in the extent to which gravity waves and gravity-wave induced transport of heat, momentum, aerosols and minor constituents control the climatological state. Our scientific objective is to elucidate the gravity wave control of the MLT. We are performing modeling and analysis to study MLT phenomena controlled by gravity waves. Specific topics include gravity wave spectra, wave-induced turbulence, wave-induced fluxes of heat, momentum, minor constituents and aerosols. We plan to analyze airglow and noctilucent cloud data for changes caused by waves and wave transports. We plan a modeling effort using a complement of steady state linear models, time-dependent nonlinear models, and eikonal models. We plan time-dependent modeling of wave-driven airglow fluctuations and changes in mean airglow intensity. We plan to study the propagation of waves through wave backgrounds to study wave filtering and the shaping of the spectrum; examine the diffusive effects of a spectrum of gravity waves on the mean state; investigate the ducting of waves by wind effects; examine the effects of wave transience on momentum deposition in the middle atmosphere; and examine the effects of local wave-mean flow interactions on tidal variability. The outcome of our work will be a quantitative assessment of wave transport effects and their importance for improving dynamical, chemical and aerosol modeling of the MLT.

Modeling Studies :

Wave-Mean Flow Interaction Model:

The present model is an existing time-dependent model that describes the vertical propagation of a wave packet and its nonlinear interaction with the mean state This model has been used to investigate the nonlinear interactions between gravity waves and tides and the evolution of the mean state following wave breakdown. The model includes dissipative losses due to radiative damping and eddy and molecular diffusion of heat and momentum. Dependent variables are separated into mean and perturbation (wave) parts. The perturbation and the mean flow both have time dependencies determined by the model equations. The interaction of the perturbation and mean state leads to time-dependent modifications of both components in a self-consistent manner. The model includes the minor constituents involved in OH airglow chemistry and the transport of these constituent caused by the wave.

<u>Progress to Date</u>:

During the present period of performance we have worked on the modification of mean-state OH-airglow minor constituents. We have calculated the mean-state mixing ratio tendencies caused by wave transport. We have also calculated the tendencies due to parameterized small-scale turbulence. We are working on achieving a steady-state balance between the wave transports and eddy diffusion.

Full-Wave Steady -State Model:

Previous work on the steady-state response of airglow to atmospheric gravity waves has involved WKB approximations to account for the vertical variation of basic-state quantities such as temperature and diffusion coefficients. This approximation is inaccurate when applied to basic states with steep gradients or waves with long vertical scales. A full-wave model realistically includes the effects of wave reflection and is required to realistically simulate wave-driven fluctuations for waves that are strongly affected by thermal gradients and wind shears.

Progress to Date:

During the present period of performance we have worked with Dr. M. P. Hickey (University of Huntsville, Alabama) to study wave-driven fluctuations of airglow $O_2(^1S)$ airglow (5577 Å) using a full-wave model of gravity wave propagation. The effects of wave trapping are clearly present for nearly evanescent waves. We have also studied the effects of background winds and temperature gradients in trapping wave energy, particularly between wind maxima. The results may have relevance for tidal trapping of wave energy.

Eikonal Model:

This new research involves an eikonal approach to simulating the effects of nonlinear interactions on wave propagation and dissipation. The approach involves propagating wave packets "test waves" through a wave background that varies in time and space. Statistics are generated by propagating different test waves through different realizations of the background. The goal of the work is to see whether an atmospheric spectrum of background waves would generate realistic spectra in the high wavenumber and high frequency part of the spectrum.

Progress to Date:

During the present period of performance we have developed the following major components of the model: Routines to specify the wave background, calculate the trajectory (path) of a wave packet, calculate the frequency and wavenumber of a wavepacket along the trajectory, and calculate the wave amplitude along the path. The model has been tested for simplified backgrounds and gives excellent agreement with the expected results.

Data Analysis:

Airglow Fluctuations Driven by Waves:

We have analyzed airglow data sets for the effects of gravity waves and to characterize gravity waves at airglow altitudes. We have examined data sets for wave spectra, the seasonality of wave amplitudes, and the relation between waves and the seasonal behavior of airglow intensity. We have also analyzed data for tides.

Progress to Date:

Tides: We analyzed observations from Hawaii during October 1993 that revealed the presence of tidal perturbations of airglow intensity and temperature in the MLT region. These results were compared with the predictions of the Thermosphere Ionosphere Mesosphere Electrodynamics Global Circulation Model (TIME-GCM). This model was recently tuned to agree with the observations from the Upper Atmosphere Research Satellite (UARS) with respect to mesosphere/lower thermosphere winds (60-200 km). We found that although the TIME-GCM agrees with UARS winds it underpredicts the diurnal, and possibly the semidiurnal, tidal temperature perturbations seen in our observations. Since the TIME-GCM only includes migrating tides, this comparison suggests that non-migrating tides may have had a significant amplitude during observation period. UARS observations of the major non-migrating diurnal mode were made just before and after the observing period. It is found that the zonally symmetric non-migrating tide alone cannot account for the discrepancy between the observations and the TIME-GCM predictions. We also analyzed continuous (24-hours per day) airglow data from Eureka (80°N) for a four-week period during polar night. We found clear indications of previously unreported very-high frequency tides. The tides had periods of 3- and 4- hours.

Gravity waves: From April, 1995 to January, 1996 a nightglow imager and an airglow photometer were collocated near Adelaide, Australia. The data obtained on more than 50 clear nights revealed seasonal changes in the airglow intensities and temperatures as well as in the gravity wave activity. These temperature data are the first seasonal results from the mid-latitude southern hemisphere mesopause region. The OH Meinel band was observed to have a rotational temperature that was warmer than the O_2 Atmospheric band in the winter. There were also summer solstice maxima and winter solstice minima in the O_2 Atmospheric band and OI(557.7) airglow intensities. The gravity wave activity, seen in the 50 to 80 km horizontal wavelength waves, was generally greatest in the OH Meinel layer and showed a semiannual variation with a strong summer solstice maximum. The relationship between gravity wave activity and airglow intensities disagrees somewhat with models. Compared to previous studies, the data suggest that there may be a difference in the seasonal variability of short and long period gravity waves.

Most Significant Accomplishments

- Development of eikonal model
- Discovery of very high frequency tides
- First characterization of small-scale gravity waves in mid-latitude southern hemisphere

Research To Be Carried Out During The Coming Year

During the coming year we plan to complete development of the time-dependent airglow model to include the time-dependent background state. We plan to complete development of the eikonal model and calculated the propagation of waves through a complex background spectrum of waves. We plan to study the non-linear effects of gravity waves in causing a diffusion of background heat, momentum and minor constituents. This work will be accomplished with an existing model of Stokes diffusion and a stochastic model to be developed. We plan to analyze the Adelaide airglow data for the directionality of wave propagation and correlate the data with University of Adelaide radar wind observations and photometer data. We plan to analyze noctilucent cloud data to be collected this summer for wave effects.

PUBLICATIONS

Hecht, J. H., R. L. Walterscheid, J. Woithe, L. Campbell, R. A. Vincent, and I. M. Reid, Trends of airglow imager observations near Adelaide, Australia, Geophys. Res. Lett, in press, 1997

Hecht, J. H., R L. Walterscheid, R. G. Roble, R. S. Lieberman, E. R. Talaat, S. K. Ramsay Howat, R. P. Lowe, D. N. Turnbull, C. S. Gardner, R. States, A comparison of atmospheric tides inferred from observations at the mesopause during ALOHA-93 with the model predictions of the TIME-GCM, Submitted to the J. Geophys. Res, 1997

Walterscheid R. L. and G. G. Sivjee, Very high frequency tides observed in the airglow over Eureka (80°N)," Geophys. Res. Lett., 23, 3651 -3654, 1996